CXCII. THE EFFECT OF COOKING ON THE DIGESTIBILITY OF MEAT.

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The question of the effect of cooking on the digestibility of foods has long been a subject of discussion. General opinion may be summed up in the words of Hutchison [1927]: "It is an error to suppose that cooking increases the digestibility of foods. That is only true of vegetable foods. The digestibility of animal foods is diminished rather than increased by cooking."

This diminution of digestibility in cooked foods is upheld by Clementini [1923] who found that when animals were fed on autoclaved meat the nitrogen balance became negative. He states however that this may partly be accounted for by the dislike shown to the autoclaved meat by his experimental animals.

Richet, Oxner and Richards [1925, 1926] state that cooked meat is of less value as a food for fish than raw meat, since fish fed on cooked meat die about the fiftieth day whilst those kept on raw meat survive. It seems possible since meat formed the sole diet in these experiments that an alteration in the vitamin content may be one of the causes of the inferiority of cooked as compared with raw meat as a fish food. A similar observation was made on the diet of Eskimos by Heinbecker [1928] who states that the Eskimo in his natural state eats practically only raw flesh and remains healthy. On the contrary it is well known that when, owing to the spread of civilisation, the Eskimo cooks his meat, scurvy breaks out.

Waterman and Finks [1920] found that rats fed on cooked phaseolin showed better growth than those fed on raw phaseolin, and Waterman and Johns [1921], continuing the work *in vitro*, found more amino-N in a digest from cooked phaseolin than from raw. They digested the protein first with pepsin and then with trypsin in order to imitate conditions in the animal body as closely as possible. This greater rate of digestion with cooked protein has been confirmed by Wallen-Lawrence and Koch [1930], who found that heat-treated milk was more rapidly digested than raw milk owing to an alteration in the whey. As is pointed out in this paper, this falls into line with other experiments on the anti-enzymic action of raw animal tissues. Hahn [1897] showed that normal blood-serum resisted proteolytic digestion more than

heated serum, and Wells [1906] found that the rate of autolysis of tissues in heated serum exceeded that in unheated serum.

In view of these findings and since raw meat is so often recommended in cases of weak digestion, whilst re-cooked meat is condemned as very indigestible, a series of experiments was carried out with meat cooked in various ways to compare the relative digestive rates.

Experimental.

Since in the normal body tryptic digestion follows on digestion with pepsin, and since the hydrolysis of protein by trypsin is more complete if carried out subsequently to peptic digestion [Cole, 1928], it was thought desirable to use both enzymes in one series of experiments. In a second parallel set, trypsin alone was used to digest the meat in an endeavour to find if cooking affected the action of one or both enzymes. The rate of hydrolysis of protein was estimated by Sørensen's formalin titration method.

In any series of experiments a large and, as far as possible, homogeneous joint was divided into four portions. One was kept raw, two were cooked so that they ceased to be purple inside and became the bright red of underdone though cooked meat; a fourth was over-cooked so that it became a uniform brown throughout its thickness. One of the correctly cooked pieces after cooling was re-heated in the oven till it also was over-cooked to the same degree as the fourth piece.

The joints were allowed to cool, any obvious fat and connective tissue were removed and the remaining protein was finely minced. 75 g. of this mince were placed in a flask, 150 cc. distilled water were added and the whole was placed in an ice-chest overnight. The next day in the trypsin experiments 150 cc. of 0·8 % Na_2CO_3 were added and the flasks were put in a water-bath at 37°. They were left 60 minutes for the flask contents to rise to the bath temperature, when 20 cc. of 10 % solution of pancreatic substance were added. The mixture was shaken, 20 cc. were pipetted into a beaker and the flask was returned to the bath. To the 20 cc. were added about 150 cc. of boiling water (to stop enzyme action), 8 drops of phenolphthalein and 30 cc. of neutralised formalin (1 part formalin: 2 parts H_2O) and the mixture was titrated with 0·1*N* H_2SO_4. At intervals the flasks were shaken and a further 20 cc. of mixture were removed and treated in the same way.

When preliminary peptic digestion was employed the following method was adopted. 75 g. of minced meat were left with 75 cc. of water in an ice-chest overnight. The next day 75 cc. of 0·4 % HCl at 45° were added, together with 15 cc. of 10 % solution of pepsin scales. This mixture was left in a bath at 37° for 2 hours. The contents of the flasks were then neutralised with solid anhydrous Na_2CO_3. To the neutralised mixture 150 cc. of 0·8 % Na_2CO_3 at 37° and 20 cc. of 10 % pancreatic substance were added, and the contents were treated as described for tryptic digests.

When grilling meat a large piece of rump steak was divided into four parts. Two of these were grilled till bright red inside, one was over-cooked till brown throughout, and one was left raw. One of the two underdone steaks was allowed to cool, and was then re-heated till warmed through, but care was taken to stop at this point. The steak was thus re-heated but not over-cooked. The four samples of meat were allowed to cool, minced and treated as described for roast beef.

For experiments on boiled meat, a large piece of lean skirt steak freed from obvious connective tissue was minced. Portions of 75 g. were weighed into flasks together with 75 cc. of water. Some were left raw, some were immersed in boiling water for 10 minutes (when all the mince had turned brown) and some for 60 minutes. Half of the samples cooked for 10 minutes were allowed to cool and then re-boiled for a further 50 minutes. The flasks, after cooling, were made up to their original weight with water to keep the volume constant, and were then treated as described for roast beef.

Results.

The first set of results in each series is shown graphically in Fig. 1.

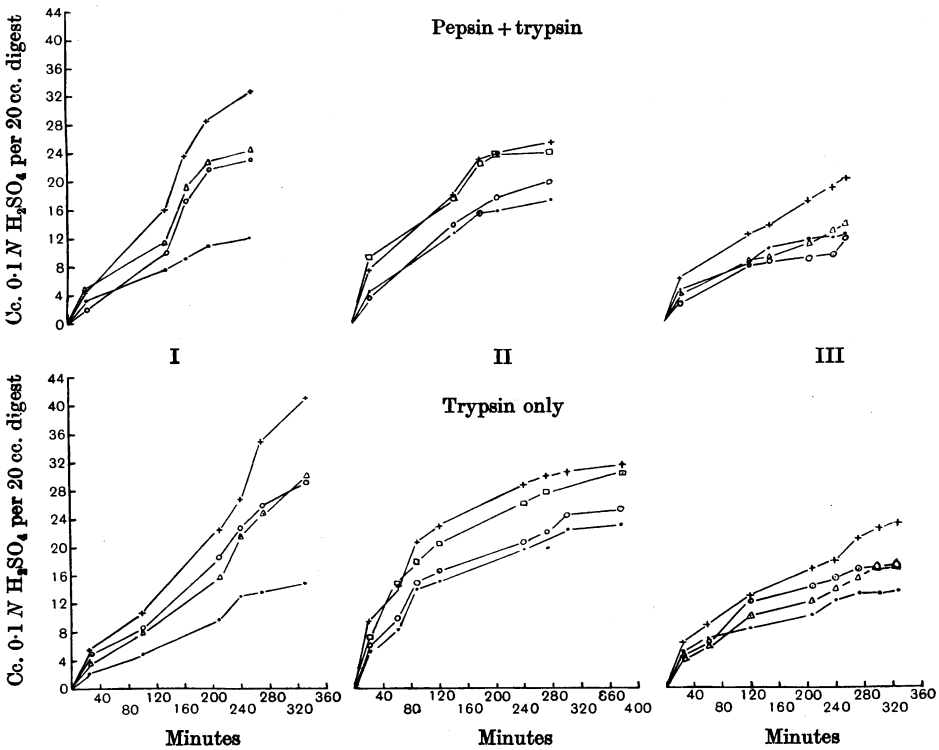

Fig. 1. I. Roast topside of beef. II. Grilled rump steak. III. Boiled skirt steak.
+—+— Cooked meat. ○—○— Over-cooked meat. △—△— Re-heated and over-cooked meat. □—□— Re-heated but *not* over-cooked meat. •—•— Raw meat.

Table I. *Roast meat (topside of beef).*

Cc. 0·1*N* H_2SO_4 per 20 cc. digest after HCHO.

Mins.	Raw				Cooked				Over-cooked				Re-heated and over-cooked			
Pepsin + trypsin:																
30	3·7	4·4	3·8	4·0	4·2	4·8	5·7	4·7	2·2	3·6	3·0	4·4	4·5	2·5	3·4	4·7
135	7·8	8·0	7·5	8·3	16·0	10·7	14·6	16·5	10·0	—	10·8	12·2	11·2	10·8	11·4	9·8
165	8·9	9·5	8·1	10·1	23·5	20·1	22·7	24·0	17·1	13·6	15·2	16·9	19·0	13·9	16·1	17·1
195	11·1	11·6	11·5	11·8	28·2	22·9	27·5	28·4	21·7	18·2	20·6	21·6	23·4	15·2	19·8	20·7
255	12·0	12·7	12·6	12·9	32·4	25·7	29·3	31·1	23·4	19·0	22·1	22·9	24·2	16·4	20·5	23·1
Trypsin only:																
30	2·3	3·7	4·0	4·1	5·7	6·1	6·0	5·4	5·4	4·7	4·2	4·9	3·7	4·5	4·2	5·0
105	4·8	6·2	5·7	8·0	10·9	16·0	12·3	12·3	8·8	9·1	10·3	9·9	8·0	8·9	11·0	10·1
210	9·6	11·1	10·1	11·7	22·5	26·2	22·7	24·0	18·9	18·3	17·9	20·2	15·6	17·2	18·1	19·3
240	12·9	13·7	13·2	13·4	26·7	32·0	27·7	27·9	23·2	23·1	22·1	24·1	21·6	22·9	22·8	23·7
270	13·8	15·8	14·4	15·1	35·2	34·3	32·1	32·0	26·2	25·7	24·6	27·6	25·1	24·3	25·1	26·5
330	14·9	16·1	15·8	15·7	41·1	36·0	36·3	33·1	29·2	28·0	27·9	28·3	29·9	27·8	28·2	27·9

In the case of roast beef (Table I), contrary to expectations there was no difference in digestion rate if trypsin alone were used or if it were preceded by pepsin. Raw meat is seen to be far less readily digested *in vitro* than roast meat. The maximum rate of digestion was obtained when meat was roasted so that when cut after cooling it appeared a bright red colour with a juicy surface. Over-cooking till the cold joint on cutting appeared brown and dry (though quite edible), markedly slowed the digestive rate, and this slowing occurred to an equal extent whether the application of heat were continuous or conducted in two successive periods.

Table II. *Grilled meat (rump steak).*

Cc. of 0·1*N* H_2SO_4 per 20 cc. digest after HCHO.

Mins.	Raw				Cooked				Over-cooked				Re-heated but *not* over-cooked			
Pepsin + trypsin:																
30	4·3	3·9	4·1	4·7	7·5	8·0	7·8	7·4	3·6	3·8	4·1	3·4	9·0	7·6	7·7	6·9
150	12·6	11·5	9·7	8·3	18·2	19·1	21·2	20·1	12·9	12·7	11·3	12·1	17·6	18·2	20·8	18·7
180	15·5	15·0	10·2	10·5	23·0	23·4	24·1	24·0	15·2	14·1	13·1	14·5	22·9	22·3	24·5	23·5
210	15·8	16·2	11·7	12·6	23·5	24·1	25·9	26·1	17·5	16·0	15·4	16·2	23·2	23·5	25·2	25·7
285	17·1	18·3	12·3	14·7	24·9	27·2	27·8	23·9	19·6	18·5	16·8	17·9	23·7	24·7	26·7	22·8
Trypsin only:																
30	5·3	4·0	4·7	5·0	9·2	8·0	8·5	8·2	5·7	5·3	4·0	4·6	7·1	8·0	7·9	8·2
60	8·2	7·8	8·5	7·9	14·4	14·7	15·1	14·6	10·2	12·2	10·2	11·8	14·8	14·4	15·2	14·3
90	13·9	11·9	12·1	12·6	20·4	18·8	19·2	20·0	14·7	14·2	13·7	13·9	17·8	18·2	17·5	17·1
120	15·1	12·0	14·4	13·9	22·8	20·8	21·7	23·1	16·6	15·8	15·9	16·0	20·6	20·9	21·0	20·2
240	19·5	18·3	18·8	17·8	28·4	28·1	27·8	28·6	20·9	19·7	20·0	20·4	26·1	27·1	26·2	27·4
270	19·7	20·2	20·0	19·2	29·6	28·9	28·4	29·2	22·2	20·6	22·7	21·9	27·9	28·0	28·4	28·7
300	22·6	21·0	20·9	21·5	30·7	30·2	29·6	29·8	24·4	22·0	23·8	23·7	30·4	28·4	29·1	29·6
375	22·7	22·3	22·3	21·9	31·6	31·1	30·9	31·7	25·3	23·0	24·0	24·9	30·7	30·3	30·0	31·0

With grilled meat again (Table II) no appreciable difference could be seen whether trypsin alone or pepsin and trypsin were employed, and in both series the digestion rate of raw meat was markedly slower than that of cooked meat. As with roast beef over-cooking retarded digestive action, but no appreciable difference could be discerned between the rate of digestion of lightly-grilled steak and that of a similar piece re-warmed but not over-cooked in the process. The slowing effect of re-cooking seen in the roast meat experiments

therefore appears to be due to the hardening of the protein rather than to the actual double application of heat with an intermediate cooling period.

Table III. *Boiled meat (skirt steak).*

Cc. 0·1*N* H_2SO_4 per 20 cc. digest after HCHO.

Mins.	Raw				Cooked				Over-cooked				Re-heated and over-cooked			
Pepsin + trypsin:																
30	4·4	2·3	3·9	4·7	6·0	6·8	6·5	5·9	2·9	3·1	2·6	3·2	4·2	3·9	4·1	4·0
120	8·3	7·9	8·0	8·5	12·3	12·0	13·2	12·7	8·1	8·4	8·5	8·7	8·2	8·0	7·9	8·5
150	10·6	10·8	9·7	11·1	13·6	14·1	14·4	13·8	8·3	10·2	11·2	10·0	8·7	10·2	10·5	10·3
210	11·7	12·0	11·6	12·3	17·0	16·9	17·0	16·5	8·8	10·9	12·1	11·4	11·3	11·8	11·4	12·0
240	11·8	12·2	11·9	12·6	18·7	17·6	18·2	18·4	9·2	11·0	11·2	11·7	12·7	12·1	12·4	11·9
270	12·2	13·0	12·4	12·9	20·0	20·5	19·7	20·4	11·9	12·1	13·6	12·3	13·5	12·7	13·1	12·7
Trypsin only:																
30	5·0	4·1	4·4	4·9	6·5	7·0	6·9	6·0	4·6	5·0	4·8	5·2	4·1	4·7	5·0	4·3
60	6·9	5·0	6·0	7·2	9·0	9·3	9·2	8·7	6·8	8·1	7·9	8·1	6·3	6·7	7·2	6·9
120	8·2	8·7	8·1	9·0	13·2	13·0	13·3	12·3	12·1	12·4	12·0	11·9	10·0	9·4	11·4	10·4
210	10·3	12·0	10·7	11·4	16·7	16·8	16·0	15·7	14·7	15·1	14·5	14·4	12·2	12·9	13·3	12·7
240	12·3	12·9	11·0	11·8	17·9	17·7	17·5	17·0	15·7	16·3	16·0	15·5	13·9	14·1	14·7	14·4
270	12·9	13·8	12·4	12·2	21·1	20·9	19·9	20·0	17·0	17·1	16·8	16·7	15·6	15·9	16·1	15·7
300	12·9	14·0	13·2	12·9	22·6	21·8	22·1	21·4	17·3	17·6	17·0	16·9	16·8	16·2	16·9	17·0
330	13·1	14·7	13·6	13·8	22·8	22·5	22·7	23·1	17·5	17·6	17·8	17·2	17·4	16·9	17·4	17·8

Similar results were obtained with boiled meat (Table III). The over-boiled mince in the set of experiments with pepsin and trypsin was digested more slowly than when trypsin alone was used. This is probably due to the fact that the boiled minced steak ran together in lumps when HCl was added and tended to do so throughout the experiment, whilst when Na_2CO_3 alone was used the meat remained in discrete particles. This aggregation was not seen with minces from grilled or roast meat.

Discussion.

From the above experiments it seems that, taking rapidity of hydrolysis as a criterion, meat when raw is in the least digestible condition. The most rapidly digested meat is that which is roasted or grilled until it is just red inside with a moist surface when cut. This point probably coincides with that at which the anti-enzymic properties of animal tissues are destroyed, whilst the hardening effect of heat on proteins has hardly come into play.

If the heating is carried beyond this point and the meat is definitely over-cooked, the rate of digestion is slowed but, unless the meat be actually carbonised, it even then appears to be more rapidly digested than raw meat. The least rapidly digested form of cooked meat found in these experiments is an over-boiled mince—the most rapidly, an underdone roast. It would therefore seem that for people with weak digestive powers or for young children the ideal form in which to administer animal protein is as underdone roast beef minced after cooking. This mince which comes from an ordinary household machine as a moist paste is very palatable.

The apparently very slow rate of digestion with boiled meat in these experiments may be due to the fine state of division of the meat before cooking,

and probably if a large joint, *e.g.* a leg of mutton, had been taken for boiling instead of minced steak, the differences between roast and boiled meats would not be so marked. Obviously it is difficult, if not impossible, to boil minced meat to a state comparable with that of an underdone roast joint. Experiments on these lines are in progress.

The decrease of digestibility in over-cooked meat appears to be due to hardening and drying of the protein since, if underdone roast or grilled meat is re-warmed but not over-cooked, its digestion rate is unaltered, but if it is re-heated until it is quite over-cooked the rate is slowed. This is in accordance with general opinion amongst cookery teachers who recommend the re-warming of meat but condemn re-cooking.

Summary.

Raw meat is digested *in vitro* much more slowly than cooked meat.

Over-cooked meat is very slowly digested as compared with underdone meat.

The maximum rate of digestion is obtained with underdone roast meat.

Re-warming underdone meat does not diminish its digestive rate. Re-heating with consequent over-cooking diminishes the rate of digestion.

The rate of digestion of meat (raw or cooked) is the same whether trypsin alone be used or pepsin followed by trypsin.

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